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✓ International conference of the principal high tension electrical systems. 7th, Paris, 1933.

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HOHEN PHILOSOPHISCHEN FACULTÄT

DER

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ZUR

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AN APPARATUS FOR THE RAPID COMPARISON OF VOLTMETERS.

BY F. A. LAWS AND W. D. COOLIDGE.

IN connection with the work of instruction in Electrical Engineering at the Massachusetts Institute of Technology, between seventy and eighty portable voltmeters and ammeters are employed. These instruments are of the best types, and the class of work demanded of the students requires that their errors be known. Consequently it has been necessary to develop a ready means of calibration. We shall here describe our apparatus for comparing direct current voltmeters with a standard instrument. This is done with the hope that the plan of the arrangement used will be of service to others who must keep track of large numbers of measuring instruments.

The apparatus to be described places at the immediate disposal of the operator any voltage between zero and three thousand. This very considerable range demands that proper safety devices be employed to protect the observer from accident and the instruments from injury. The former is rendered the more imperative by the fact that the apparatus is used by students as well as by instructors, and is of necessity situated in a crowded laboratory.

In the diagram (Figure 1) D_1 and D_2 are two similar dynamos, built by the Holtzer Cabot Co. The frames are those of stock machines; the fields are separately excited from a 110-volt circuit; the armatures are specially wound, so that at 1,600 revolutions per minute each machine has an E. M. F. of 1,500 volts, the current capacity being $\frac{1}{4}$ ampere. In order that there shall be little fluctuation of the voltage, the commutators have a large number of segments, 150.

The dynamos are connected to an intermediate shaft, which is supported by independent, self-oiling bearings, and carries a balance wheel, W, weighing 100 lbs.; flexible couplings, c_1 and c_2, are provided.

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Proceedings of the Americar demy of Arts and Sciences.

Vol. XXXIX. N . November, 1903.

CONTRIBUTIONS FROM RESEARCH LABORATORY OF PHYSICAL CHEMIS OF THE MASSACHUSETTS INSTITUTE ECHNOLOGY. — No. 1.

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I. — DESCRIPTION E APPARATUS. RESULTS WITH SODIUM AND SSIUM CHLORIDE UP TO 400°.

By Arthur A ES and William D. Coolidge.

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A paper to be presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 25, 1912

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(*Subject to final revision for the Transactions.*)

METALLIC TUNGSTEN AND SOME OF ITS APPLICATIONS

BY W. D. COOLIDGE

Tungsten does not occur as such in nature; but in the form of compounds it is pretty well distributed. The most important ores are sheelite or calcium tungstate and wolframite or iron-manganese tungstate. The principal source of the ore at this time in this country is Boulder County, Colorado.

From the ore it is a simple matter to get the yellow oxide (trioxide) of tungsten. And the trioxide may be reduced in various ways, as with hydrogen, zinc and carbon, to metallic tungsten. The product so obtained is in the shape of a powder ranging in color from gray to black depending upon the fineness of its state of subdivision.

Owing to its very high melting point, it was for a long time impossible to get the pure powdered metal into the form of a dense coherent homogeneous mass. Two Austrians, Messrs. Just and Hanaman[1], working in Vienna, finally succeeded however in producing the pure metal in this condition and in filamentary form, and by using it as an incandescent filament became the inventors of the tungsten lamp.

One of their processes consisted in first mixing the finely divided tungsten powder with a carbonaceous binding agent. The plastic mass so obtained was then extruded through a small orifice. The resulting thread was heated in the absence of air, to carbonize the binder. The fragile body so produced consisted of tungsten powder and carbon and was electrically conducting. If it had been used in this condition it would have been

1. U. S. Patent No. 1,018,502.

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A POWERFUL RÖNTGEN RAY TUBE WITH A PURE ELECTRON DISCHARGE

W. D. COOLIDGE

[Reprinted from the PHYSICAL REVIEW, N.S., Vol. II., No. 6, December, 1913.]

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A SUMMARY OF PHYSICAL INVESTIGATION WORK IN PROGRESS ON TUBES AND ACCESSORIES

BY
W. D. COOLIDGE

Reprinted from the December, 1915, issue of the American Journal of Roentgenology
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HARD X-RAYS

By W. D. COOLIDGE

Reprinted from the April 1915 issue of The American Journal of Roentgenology

By the hardness of X-rays we refer to a quality and not to a quantity factor. In using the term we have in mind that quality which enables the rays to pass through matter. The physicist has shown that the X-Rays are like ordinary light, differing from it only in the vibration frequency or wave-length. The X-rays owe their power of penetrating objects opaque to ordinary light, to their high vibration frequency, and the greater this is the harder the rays are.

In determining the vibration frequency or hardness of the X-rays, there are two things only that count, the atomic weight of the target material and the velocity of the projectiles, the electrons, which bombard it.* Other things being equal, the higher the atomic weight of the target metal the better suited it is to the production of the most penetrating radiations. Uranium has the highest atomic weight of all of the elements (238) and would therefore be best suited to serve as a target for the production of very penetrating X-rays were it not for certain limitations, such as its relatively low melting point. The consideration of this and of other properties, such as heat conductivity and vapor pressure, has led to the general adoption of tungsten (with an atomic weight of 184) as a target material. This step taken, there is then only one factor at our disposal, namely, the velocity of the electrons constituting the cathode ray stream. The higher this velocity is the more penetrating will be the X-rays produced.

Now the velocity of the electrons is determined by the voltage impressed upon the tube, and increases with the square root of the latter. The point deserving special emphasis is this, that neither the type of tube, nor the tube design, nor the vacuum, nor the milliamperage flowing through the tube, has anything to do with the simple statement that, with a given target, the only thing which affects the penetration of the X-rays produced is the voltage which is actually impressed upon the tube, and the higher this is the higher the penetration is. Any definite value of voltage implies of necessity a corresponding X-ray penetration.

If our X-ray generators were only constant potential sources, like the static machine and the storage battery, the whole matter would really seem as simple as it is. We would then never need to ask the question as to whether one tube was or was not giving X-rays of the same penetration as another tube, provided the two were being operated at the same voltage, as the mechanism of X-ray production would make it so of necessity.

Unfortunately for perfect simplicity, most X-ray work is done on variable instead of on constant voltage. But the simple fact remains that at any instant of time the penetration of the X-rays is bound to be that corresponding to the voltage on the tube at that moment, and this regardless of the type of tube involved or of the condition of that tube. A curve showing the voltage on the tube at each instant of time would then tell us how the penetration changed from instant to instant. We are then, in general, dealing with a mixture of rays varying among themselves in hardness to correspond with the varying potentials impressed upon the tube.

A very fertile source of discordant results in the past is the fact that the penetration

*There is really a third factor, namely, the nature of the collision between the electron and the target. The face of the target, even though highly polished, is, when compared with a particle the size of the electron, exceedingly rough and porous. As a result, some electrons collide in such a way that they are brought to rest much more suddenly than others of the same velocity, and the former therefore produce harder X-rays than the latter.

This factor has been omitted from the discussion for the reason that it does not influence our general conclusions and is, moreover, entirely outside of our control.

For the sake of simplicity, the writer is also not taking into account the characteristic rays emitted by the target material, and is referring only to the so-called independent radiations.

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ROENTGEN RAYS FROM SOURCES OTHER THAN THE FOCAL SPOT IN TUBES OF THE PURE ELECTRON DISCHARGE TYPE

By W. D. COOLIDGE
and
C. N. MOORE

REPRINT
From Issue of April, 1917

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PHYSICAL INVESTIGATION WORK IN PROGRESS ON TUBES AND ACCESSORIES

BY
W. D. COOLIDGE, PH. D.

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THE AMERICAN JOURNAL OF ROENTGENOLOGY
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OIL-IMMERSED X-RAY GENERATING OUTFITS

BY

W. D. COOLIDGE

Research Laboratory, General Electric Company
SCHENECTADY, N. Y.

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X-RAY WORK AT SCHENECTADY

By Dr. W. D. Coolidge.

(*Read July* 15*th*, 1920).

Mr. President, members of the English Röntgen Society, ladies and gentlemen, it is a very great pleasure to me to be here this evening.

I want first of all to pay my tribute to the wonderful pioneer work that has been done in the field of radiology and the allied fields of physical science by English physicists. I need to refer only to such names as Crookes, J. J. Thomson, Rutherford, the Braggs, Moseley, Darwin, and Richardson; there are scores of others I could mention. It seems very strange to me, on thinking the matter over, that so large a proportion of the pioneer work in these fields has been done by Englishmen. I do not know why this is, but we must certainly try to learn your secret.

It is a relatively simple matter to get men to do research work in applied science, applying to commercial ends the principles established by others, for such work pays for itself. It is not nearly as important, however, as work leading to the establishment of new principles. To appreciate this fact, one has only to think of the effect on the world's progress of the work of a Clerk Maxwell or a J. J. Thomson or an Ernest Rutherford.

In the United States at the present time, industrial research is going ahead by leaps and bounds. You also are now actively interested in applying scientific research to commercial purposes. It is to be hoped that, as you go ahead along this line, you will still continue the more unselfish kind of research which you have been and are doing so well.

I come from the industrial research laboratory of a large industrial organization (the General Electric Company) which manufactures, on the one hand, apparatus of all sizes for the production of electric power. The laboratory was started in 1900 by Dr. W. R. Whitney. Under his leadership it has grown rapidly and steadily, even through periods of business depression, until to-day the staff consists of about three hundred people, some sixty of whom have had a college training.

The problems which come to such a laboratory are extremely varied in character. In general, the men are given a great deal of freedom both in their choice of problems and in their method of attack. One type of man analyzes his problem logically and plans out a method of attack. Another type of man tries everything that looks good to him, and then everything else that he can think of. Strange as it may seem, both methods in good hands, yield good results. One type of man seems to need a working theory to give him sufficient enthusiasm to try his experiment, while the other type is glad to try any experiment that he has never tried before. If a man does not get the result which he seeks, he probably gets some other result which is of value either in itself or for its bearing on some other problem of the laboratory.

For the sake of mutual assistance and mutual inspiration, every member of the staff is encouraged to know as much as he can about what every other man in the laboratory is doing.

I want to talk this evening about the work of our laboratory in the X-ray field, and will limit myself still further to the X-ray field as applied to medicine.

The story naturally begins with the production of ductile tungsten, the material used first at the focal spot and, later, in the cathode of the X-ray tube.

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THE KEARSLEY STABILIZER*

By W. D. COOLIDGE, PH.D.

Research Laboratory, General Electric Company

SCHENECTADY, NEW YORK

THE milliamperage which will pass through a hot cathode roentgen-ray tube increases very rapidly with the temperature of the filament and hence with the heating current. To avoid fluctuations in milliamperage, in all of the early installations a storage battery was used as a constant source of heating current. The storage battery called for a good deal of attention and was, for various reasons, far from ideal for the purpose. It has been almost completely superseded by the "filament transformer." This has been more convenient, but owing to line-voltage fluctuation, has resulted in greater variability in the milliamperage passing through the tube.

In an earlier article[1] the author has alluded to attempts to hold the filament current constant by means of magnetos, boosters, iron wire ballasts, and various other devices, and finally by means of a special constant potential transformer. The last named device had no time lag and functioned very well, but took a pretty heavy current—often 18 to 20 amperes.

The above efforts were all directed toward the suppression of fluctuations in milliampereage due to causes external to the tube itself. Even with constant filament temperature, changes in milliamperage may take place due to vacuum changes in the tube. Certain gases, when liberated from the electrodes or glass walls, will cause a diminution in the electron emission from the filament, and hence in the milliamperage.

Mr. W. K. Kearsley, Jr., has devised a stabilizer[2] which works on an entirely different principle and is much more ambitious in its aim. It does not attempt to hold filament current constant but, rather, automatically varies it as required to maintain constant milliamperage through the tube. It accomplishes this result regardless of line-voltage changes and regardless of internal vacuum changes. The following description of this stabilizer is taken from Mr. Kearsley's article:

"The stabilizer is operated directly by the high tension current which flows through the *x*-ray tube. Any change in this high tension current causes the stabilizer to act directly on the current flowing through the filament. If for any reason the high tension current through the tube tends to drop, the stabilizer immediately increases the filament current sufficiently to prevent the drop. The same holds true for a rise in high tension current; the filament current in this case is immediately lowered enough to keep the milliamperage at the desired value.

Figure 1 shows diagrammatically the principle upon which the stabilizer operates. A is an electromagnet which is connected directly into the high tension circuit. All of

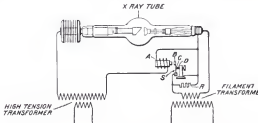

FIG. 1.

the high tension current passes through this magnet. B is an iron armature which is free to vibrate when current passes through the

[1]A summary of physical investigation work in progress on tubes and accessories. AM. J. ROENTGENOL., December, 1915, p. 891.

[2]W. K. KEARSLEY, JR. A new type of stabilizer for use with the Coolidge tube. This was described by Mr. Kearsley in a paper read December 15, 1920, at the Chicago meeting of the Radiological Society of North America.

*Read at the Midwinter Meeting of the Eastern Section of THE AMERICAN ROENTGEN RAY SOCIETY, Atlantic City, N. J., January 28, 29, 1921.

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HIGH VOLTAGE X-RAY WORK

BY W. D. COOLIDGE, PH. D. AND W. K. KEARSLEY, JR,

Research Laboratory, General Electric Company
SCHENECTADY, NEW YORK

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HIGH VOLTAGE CATHODE RAYS OUTSIDE THE GENERATING TUBE

W. D. COOLIDGE
RESEARCH LABORATORY, GENERAL
ELECTRIC COMPANY, SCHENECTADY

SCIENCE PRESS

Reprinted from SCIENCE, November 13, 1925, Vol. LXII, No. 1611, pages 441-442.

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THE PRODUCTION OF HIGH-VOLTAGE CATHODE RAYS OUTSIDE OF THE GENERATING TUBE

BY

W. D. COOLIDGE, Ph.D.

Assistant Director, Research Laboratory, General Electric Company

SOME EXPERIMENTS WITH HIGH-VOLTAGE CATHODE RAYS OUTSIDE OF THE GENERATING TUBE

BY

W. D. COOLIDGE, Ph.D., and C. N. MOORE

REPRINTED FROM THE JOURNAL OF THE FRANKLIN INSTITUTE
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CATHODE-RAY AND ROENTGEN-RAY WORK IN PROGRESS

By
W. D. COOLIDGE, PH. D.

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VOL. 33, NO. 11 NOVEMBER, 1930

"The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds, they shape themselves and go."
—Tennyson

Shovels, however, work quicker than Nature when the mountain contains copper!
(See p. 600)

In This Issue: *Temperature Effects on Turbine Materials* *Corona Losses* *X-ray Apparatus* *Short Cables and Voltage Surges* *Elevator Calculations* *Series Capacitors* *Circular Corrugations* *Current Transformers* *Cupola Blowing* *Mining Equipment*

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THE DEVELOPMENT OF MODERN X-RAY GENERATING APPARATUS

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By
DR. W. D. COOLIDGE

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October, 1921 Schenectady, N. Y. No. 598

HIGH VOLTAGE CATHODE RAY AND X-RAY TUBES AND THEIR OPERATION

By
W. D. COOLIDGE, L. E. DEMPSTER and H. E. TANIS, JR.

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A HIGH VOLTAGE INDUCTION COIL AND CASCADE TUBE ROENTGEN-RAY OUTFIT

By
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EXPERIMENTAL STUDY OF CATHODE RAYS OUTSIDE OF THE GENERATING TUBE

By
W. D. COOLIDGE AND C. N. MOORE

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THE CONTRIBUTIONS OF SCIENCE TO INCREASED EMPLOYMENT

SCIENCE MAKES JOBS—Dr. Karl T. Compton

SCIENCE AND INDUSTRY—Dr. Frank B. Jewett

THE SERVICE OF SCIENCE—Dr. Robert A. Millikan

SCIENTIFIC DEVELOPMENTS AND THEIR APPLICATION—Dr. W. D. Coolidge

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Reprinted from THE SCIENTIFIC MONTHLY, April, 1934, Vol. XXXVIII, pages 297-309.

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RESEARCH IN A LARGE INDUSTRY

By
WILLIAM D. COOLIDGE

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RESEARCH AND INVENTION

Statement of Dr. William D. Coolidge, Director of the Research Laboratory of the General Electric Company, before the Temporary National Economic Committee.

We think you will find interesting the enclosed testimony which Dr. William D. Coolidge, of the General Electric Research Laboratory, gave recently before the Temporary National Economic Committee. It surveys many of the paths that research is following in its efforts to create "More Goods for More People at Less Cost."

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Reprinted from SCIENCE, November 6, 1942, Vol. 96, No. 2497, pages 411–417.

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THE ROLE OF SCIENCE INSTITUTIONS IN OUR CIVILIZATION[1]

By Dr. WILLIAM D. COOLIDGE

VICE-PRESIDENT AND DIRECTOR OF RESEARCH, GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.

Mr. President, Members of the Board of Directors of Ursinus College, Members of the Faculty, Members of the Student Body, Dr. Pfahler, Ladies and Gentlemen:

We are met here to-day to dedicate this new temple of science—to dedicate it to the service of mankind and to give it a name—a name worthy of the inspiring tradition which shall with the years grow up around it.

In our evaluation of the importance of this event we are more in danger of under- than over-estimation. We can, of course, judge the future only by the past. So let us think of the consequences of similar occasions which have already taken place. To mention only a few examples drawn from the field of physical and chemical science:

Once upon a time there was doubtless a dedication ceremony for the physics institute of the University of Warzburg, and it was in that laboratory that Roentgen later discovered the x-rays and published his results in a series of papers which have had so profound an influence on science and on our civilization. It is of course the man rather than the institution to whom we give most of the credit. The fact remains, however, that the institution attracted him and he was, perhaps unconsciously, inspired by its traditions.

In the same way consider the importance of the founding of the Royal Institution, where Faraday did his work on electromagnetic induction; and of the Albany Academy, where Joseph Henry made his great contributions in this same field. Our whole electrical industry is based on the work of these two men. Here again, although we give most of the credit to the men, as before, we can well question whether they would have had this same tremendous influence in our civilization had not others before them created and dedicated to science the laboratories in which their work was done.

Sometimes, as in the case of Madame Curie and her discovery and isolation of radium, we see the work done under such miserable physical conditions that we may well feel that it could have been done much easier somewhere else. The fact still remains, however, that the creation and the dedication of the institution in question were links in a chain without which the work would probably not have been done by the person and at the time period in question.

Countless other similar instances could be cited in which the dedication to the cause of science of a new laboratory or the creation of a new scientific society has constituted the beginning of a great tradition.

Over forty years ago, in the General Electric Company, a group of four men consisting of Elihu Thomson, E. W. Rice, C. P. Steinmetz and A. G. Davis, were so impressed by the consequences of the fundamental scientific work carried on in college laboratories that they started what was one of the first *industrial* research laboratories in this country—a step which has since been followed by some two thousand other manufacturing organizations.

I have been in close touch with the General Electric Research Laboratory from the beginning, and, since taking over its direction, I have been greatly impressed by the strength of the tradition which has grown up around it—a tradition derived from the great men who had the vision to start it and to sponsor it through its early years, and from Dr. Willis R. Whitney, who directed it throughout the formative period of its existence, who saw the value of cooperation and secured it, who saw to it that recognition was always given to the individual and not merely to the institution, who insisted that all worth-while results should be published promptly, instead of being kept secret in what had been the time-honored way. During my incumbency in this office I have been constantly aware of the force of that tradition—a force like that inherent in the momentum of a heavy and rapidly moving body. Had I been so disposed at any time, I would have found it very difficult to do anything which would have tended to weaken that virile and inspiring tradition.

Just as the tradition of our laboratory started with the characters and achievements of the men whose names were first associated with it, so the tradition of this laboratory starts with the characters and achievements of the men responsible for its existence and takes on to-day an intimate association with the life of the man whose name you have given it.

I feel competent to speak to you on the value of that name to the tradition of this laboratory.

It is the name of a great pioneer in the application of physical science to the diagnosis and treatment of human disease. It is the name of a man to whom countless sufferers from human ills owe their lives, their health and their happiness. It is the name of a man who has not only practiced and advanced an

[1] Founders' Day address at the dedication of the Pfahler Hall of Science, Ursinus College, October 13.

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Roentgen-Ray Tubes

by

W. D. COOLIDGE
and
E. E. CHARLTON

GENERAL ELECTRIC
Research Laboratory
SCHENECTADY, NEW YORK

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HIGHLIGHTS OF THE PAST AND A CHALLENGE FOR THE FUTURE

BY

W. D. COOLIDGE

SCHENECTADY, NEW YORK

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Roentgen Rays: Tubes

W. D. Coolidge and E. E. Charlton

Supplement to W. D. Coolidge and Z. J. Atlee, Roentgen Rays: Tubes, vol. I, pp. 1395–1401.

Advances in this field have been chiefly in the design of tubes for roentgenography and in the development of tubes for high-energy electron accelerators. An improved model of a rotating target tube for use in roentgenography is shown in Fig. 1. The target may be rotated by an induction motor whose stator is without and whose rotor is within the tube.

Betatron and Synchrotron Roentgen-Ray Tubes

In betatrons and synchrotrons which permit generation of roentgen rays of many millions of volts, the roentgen-ray tube becomes toroidal in form with an oval cross-section. The electrons in these tubes, to gain their energy, make the circuit of the tubes many times and are then deflected from their orbits so that they strike the target and generate roentgen rays.* These tubes have the same high vacuum as other modern roentgen tubes and, like them, a thermionic source of electrons. Through use of an intermediate electrode they are given an initial energy of a few kilovolts before the betatron- or synchrotron-accelerating action.

Betatron acceleration is obtained by the electric field produced by a time-varying electromagnetic field. The betatron roentgen-ray tube consists of a hollow toroid of glass or other insulating material about 18 in. in diameter for the 20 000 000-v and 6 ft in diameter for the 100 000 000-v sizes. The tubes may be built either as unitary structures or in sections cemented together and continuously pumped. The 100 000 000-v tube is shown in Fig. 2. It consists of 16 pie-shaped sectors of heat-treated borosilicate glass having an elliptical cross-section 8 × 4⅞ in. The ends of the sections

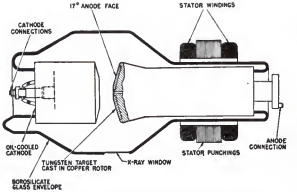

Fig. 1.—Rotating target tube with stator in position.

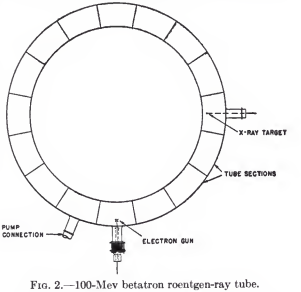

Fig. 2.—100-Mev betatron roentgen-ray tube.

* See Kerst and Skaggs—Accelerators: High-Energy; Betatron.

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A PLEA FOR MORE FUNDAMENTAL RESEARCH EFFORT

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WILLIAM D. COOLIDGE

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A HALF CENTURY'S DEVELOPMENT OF X-RAY GENERATORS

BY

W. D. COOLIDGE

SCHENECTADY, NEW YORK

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MY EARLY WORK IN TUNGSTEN

BY

DR. W. D. COOLIDGE

SCHENECTADY, NEW YORK

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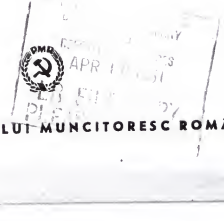

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ПО ДЕЛАМ СТРОИТЕЛЬСТВА

ИНСТРУКЦИЯ
ПО ЗАЗЕМЛЕНИЮ ПЕРЕДВИЖНЫХ СТРОИТЕЛЬНЫХ МЕХАНИЗМОВ И ЭЛЕКТРИФИЦИРОВАННОГО ИНСТРУМЕНТА

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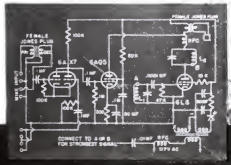

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Ленинградское отделение
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Р. М. СУЛИЕВ и С. М. ЗАРАЕВОВ

Магнитный осциллограф МИЗП-35

Ленинград — 1961

Mutilated Item
—No Call #

Erreger 5 cm Dm. — $\lambda = 74$ cm.
Drahtdistanz = 1,7 cm.

Fig. 4.

Grundschwingung — 2 Bäuche.

Fig. 5.

Grundschwingung — $1^1/_2$ Bäuche.
Einfluss von Drahtdurchmesser deutlich zu sehen vor der ersten Brücke. Hier (bei a) sind die 0,1 mm dicken Lecherschen Drähte an die 1 mm Erregerdrähte gelöthet.

Fig. 6.

I. Oberschwingung — 3 Bäuche.

Fig. 7.

Grundschwingung — 3 Bäuche.
Zeigt Einfluss des umgebenden Mediums auf die Wellenlänge. Ein langer Glasstreifen wurde unter und in Berührung mit den Drähten gehalten. λ ist von 74 cm auf 40 cm niedergebracht.

Fig. 8.

Grundschwingung — 2 Bäuche. — Bei Verwendung von engen Blechstreifen anstatt Drähten. — Distanz zwischen den Streifen = 0,6 cm.